



Proposed NASA-ISRO SAR Mission

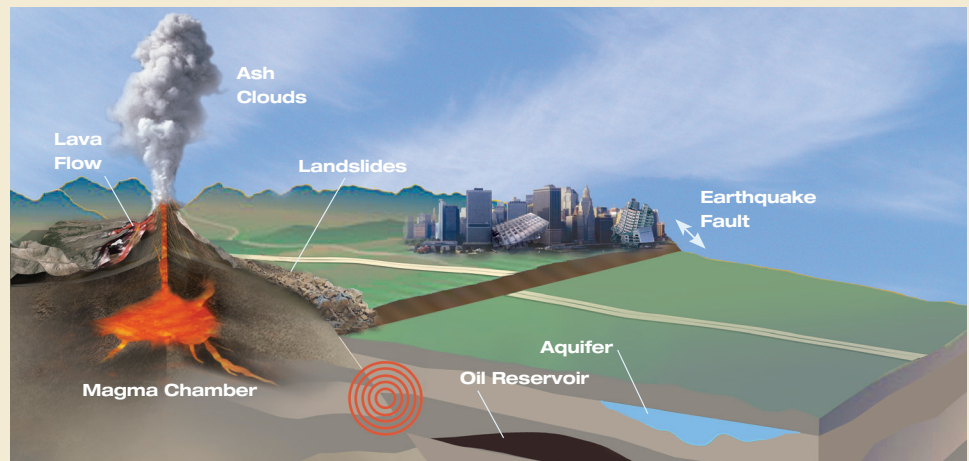


Illuminating Earth's Dynamic Surface and Interior

NISAR would measure surface deformation to determine the likelihood of earthquakes, volcanic eruptions, and landslides, and monitor groundwater, hydrocarbon, and sequestered CO₂ reservoirs.

Earth's Hazards and Resources

Why does our planet sometimes threaten us with earthquakes or volcanic eruptions? Can I depend on fresh water to flow from my tap each morning? Do we have the best possible information needed to manage our resources and potential disasters? We are often reminded that disasters occur unexpectedly, but extraordinary measurements of processes leading to disasters would help us address these questions, prepare for natural disasters, and sustainably manage Earth's resources.

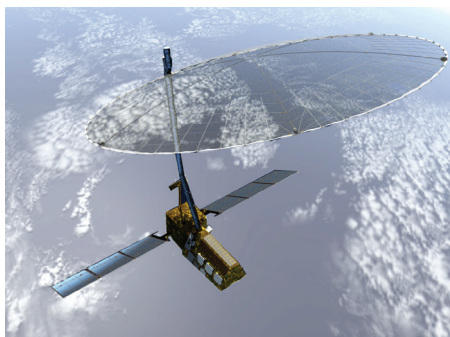


Addressing an Increasing Exposure to Natural Disasters

Society's exposure to natural hazards is rapidly increasing. Overdue large earthquakes will be costly and threaten densely populated regions on the U.S. western coast, home to about 50 million citizens. Volcanic eruptions also endanger many areas of the Earth and often disrupt air travel. Water is an increasingly scarce resource, and water storage and distribution systems must be safe and resilient for current and increasing needs.

Many hazards subtly change and deform the land surface preceding catastrophic events such as earthquakes and volcanic unrest. The best way to properly prepare for, mitigate, and respond to nature's disasters is to detect, measure, and understand these slow-moving processes before they either trigger a major disaster or compromise our natural resources. This requires relevant, comprehensive, detailed, and accessible observations collected over time of subtle but detectable motions.

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Artist's concept

The Proposed NISAR Mission — All-Weather Day and Night Imaging

Orbiting radar captures the movements of the Earth over time and with enough detail to reveal what is happening below the surface. Radar penetrates clouds and operates day and night. It produces images with resolution to see local changes and has broad enough coverage to measure regional events. The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), would acquire images of surface changes globally with millimeter accuracy and meter-scale resolution. Rapid sampling over years to decades would allow for understanding processes leading to disasters and for rapid response following them. NISAR's unprecedented coverage in space and time would reveal forces acting within the Earth and on its surface far more comprehensively than any other measurement method. The detailed observations would reveal information about the evolution and state of the Earth's crust, allowing us to better manage resources and prepare for and cope with hazards.

Mitigating Disasters and Sustaining Resources

Natural disasters often occur abruptly and without notice. Earthquakes, volcanoes, and landslides are sudden events that can cause billions of dollars in damage and extensive loss of life. Subsidence from water, oil, or gas withdrawal, faulting, or underground dissolution of limestone can have major impacts on agriculture, levees, and our built environment.

Forces deep within the Earth drive motion of the tectonic plates, causing earthquakes and volcanoes while shaping our landscapes. Withdrawal, injection, and movement of fluids at depth also cause small but detectable motions of the Earth's surface.

It is crucial for our society and economy to mitigate losses from disasters. We need informed decisions in order to carry out effective mitigation and make the most of our resources sustainably and economically. By measuring motions and other changes of the Earth's surface, we can understand processes occurring at depth and disentangle other impacts.

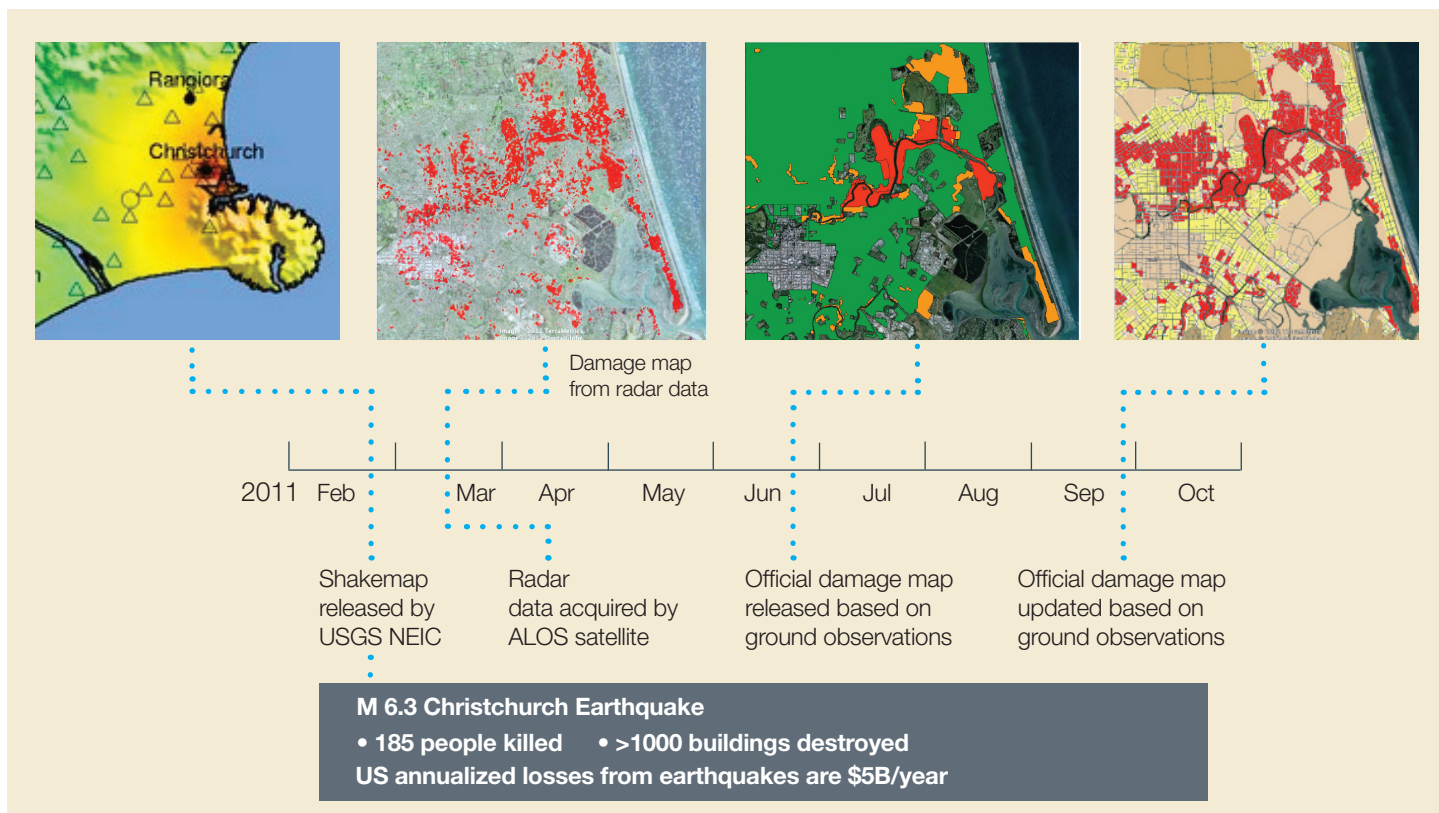
Benefiting Forecasting, Response, and Resource Management

Natural hazards will continue to threaten densely populated regions of our country. NISAR's global and rapid coverage would provide unprecedented opportunities to mitigate or assess widespread damage. Detecting Earth surface motions of our planet and its resources would help illuminate the processes occurring deep within.

A mission with open access to data adds flexibility to meet far more scientific, societal, and commercial goals. Science-based management and storage of fresh water and energy sources would allow us to use the available resources more efficiently and sustainably.

Rapid Building-Scale Damage Assessment

Following the February 2011 earthquake in Christchurch, New Zealand, a damage map was produced by comparing before and after radar images from the Japanese Advanced Land Observing Satellite (ALOS) satellite. This method detected building damage, liquefaction, and a small landslide. The results compare favorably to official maps, which were produced later. NISAR maps would allow initial damage estimates to guide ground inspection damage assessment.



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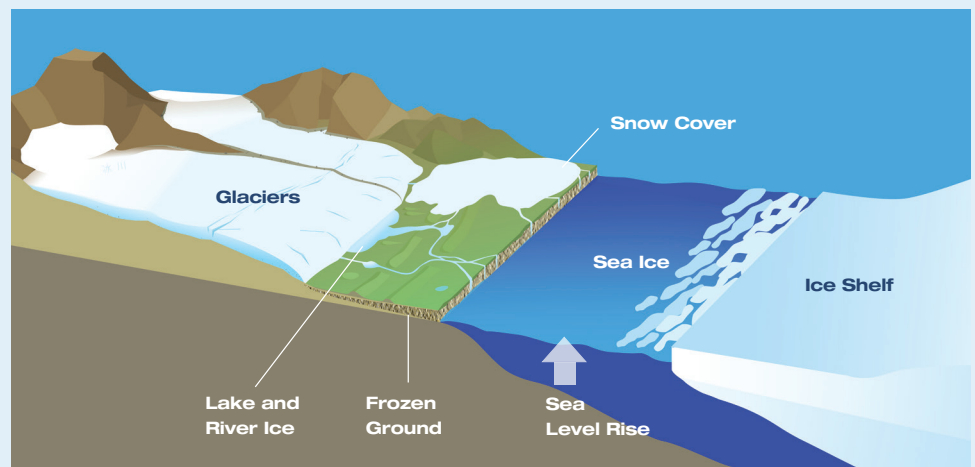


Understanding Earth's Cold Regions

NISAR would determine how climate and ice masses interrelate and raise sea level and would measure changes in sea ice, snow extent, permafrost, and surface melting.

Impacts of Earth's Remote Ice

Perhaps you imagine the polar ice sheets as icy white blankets at the ends of the Earth, static and majestic, but far removed from your daily life. In reality, these areas are among the most dynamic and rapidly changing places on Earth, where wind and currents move ice over the seas, and the forces of gravity disgorge huge icebergs to the ocean. These distant changes have very real local consequences of climate feedbacks and rising sea level.

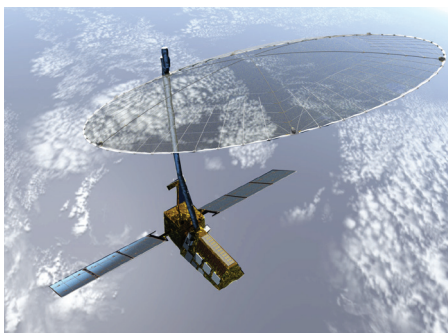


Assessing Society's Exposure to Diminishing Ice

For over a hundred years, scientists have considered diminishing glaciers and sea ice to be an early indicator of global warming. Satellite observations collected over the past three decades now show that the summer sea ice cover is decreasing drastically and may vanish entirely within the next decades. At the same time, ice sheets and glaciers are already melting fast enough to be the largest contributors to sea level rise, with a potential

to raise sea level by several tens of centimeters or more in the coming century. The loss of sea ice cover will have a profound effect on life, climate, and commercial activities in the Arctic, while the loss of land ice will impact an important source of water for millions of people. Collectively, these effects mean that despite its remote location, changes in ice have global economic and health implications as climate changes.

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Artist's concept

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Orbiting radar captures extent and motions of land and sea ice over time and with enough detail to reveal subtle changes. Radar penetrates clouds and operates day and night. It produces images that are detailed enough to see local changes, and has broad enough coverage to measure regional trends. The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), would acquire images of ice sheets, glaciers, and sea ice globally. Rapid sampling over years to decades would allow for understanding flow and changes over time. NISAR's unprecedented coverage in space and time would reveal response of ice masses far more comprehensively than any other measurement method. The detailed observations would reveal information that would allow us to better manage resources and prepare for and cope with global change.

Improving Sea Level Projections

Disintegrating ice sheets and retreating glaciers raise sea level, yet predicting future sea level changes is difficult at present. Rising sea level will displace millions of people and adaptation will be costly. Recent observations provide only isolated snapshots of ice sheet velocity and changes, and current missions map large-scale ice sheet changes while missing many fast moving glaciers with large thinning rates. NISAR would provide systematic measurements allowing short-term variations and long-term trends to be measured. NISAR would provide a time history of ice sheet and glacier behavior. It would provide precise measurement of the changing position of ice sheet grounding lines. Understanding ice sheet and glacier behavior and changes would improve projections of sea level rise from melting glaciers and ice sheets. Accurate sea-level projection would improve planning of sea walls, dikes, and other mitigation strategies.

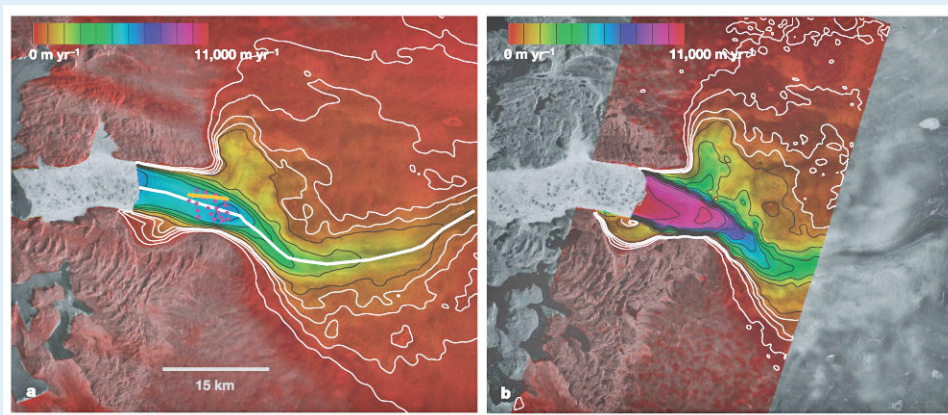
Tracking Sea Ice and Monitoring Permafrost

Arctic sea ice has thinned and its summer extent has reduced by as much 50 percent over the last several decades. By contrast, sea ice cover in the Southern Ocean may be increasing slightly in extent, but there is very little information regarding its deformation and thickness distribution. The thinning and retreating Arctic ice cover is changing the economy of local communities by causing a shift in the patterns of marine ecology and an increase in winds and waves, as well as stimulating interest in petroleum development and shipping. NISAR would provide key data necessary to make informed environmental and economic decisions. NISAR would provide the most complete measurements of rapidly changing sea ice motion and thickness of both polar regions. Understanding the causes and mechanisms of its loss requires knowledge of ice thickness distribution, sea ice types, and sea ice dynamics. Melting permafrost releases methane to the atmosphere, erodes soil, and impacts surface water distribution and stability of infrastructure. NISAR would measure heave and thaw in the near-surface active layer of permafrost.

Mapping Ice Sheet Flow

Radar measurements from the Canadian RADARSAT mission show the rapid speed up of Jakobshavn Isbræ in Greenland between February 1992 and October 2000. Over the last decade, glaciers in Greenland have sped up on average by more than 30 percent. NISAR would allow monitoring of ice sheets in Antarctica and Greenland as well as glaciers throughout the world.

The images are from Ian Joughin, Waleed Abdalati, and Mark Fahnestock, "Large Fluctuations in Speed on Greenland's Jakobshavn Isbrae Glacier," *Nature* 432: pp. 608–610.



The economic impact of sea level rise on the US will exceed \$20B.

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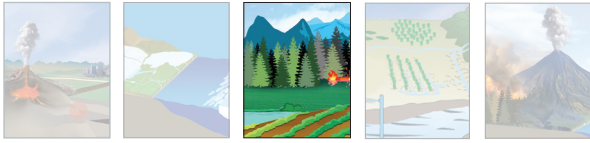
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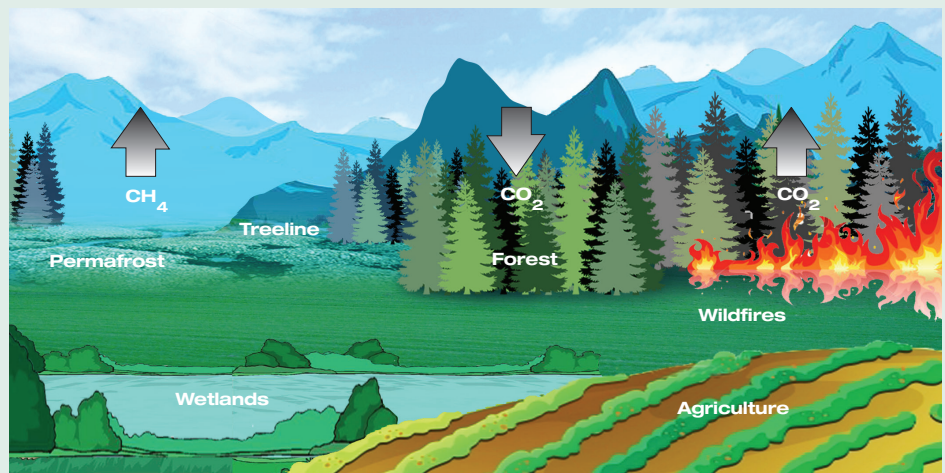


Monitoring and Managing Our Terrestrial Ecosystems

NISAR would determine the contribution of Earth's biomass to the global carbon budget and characterize ecosystem disturbance and impacts on biodiversity.

Landscapes Under Pressure

We depend on our forests, agricultural landscapes, and freshwater systems, but our landscapes are under increasing pressure. Large-scale global deforestation is causing increases in greenhouse gas fluxes. Farmers are converting patches of forests to agriculture. Urban areas are expanding into surrounding natural forests. It is imperative to fully understand the connections between human natural resource management and ecosystem responses. To protect Earth and our future, we urgently need a local-to-global-scale assessment of Earth's landscapes.

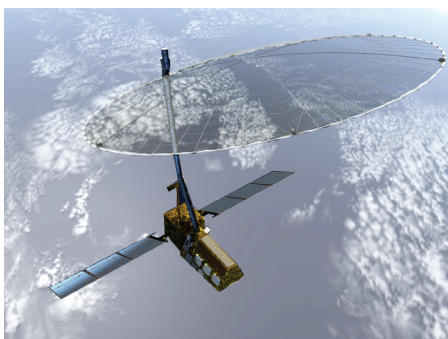


Monitoring Ecosystems for Managing Natural Resources

The world's growing population is experiencing unprecedented changes to our climate through intensifying events such as floods, droughts and wildfires, hurricanes and tornadoes, and insect infestations and related health effects. These impacts are putting pressure on our landscapes and ecosystems

that generate food, fiber, energy, and living spaces for a growing global population. It is imperative to understand the connections between natural resource management and ecosystem responses to create a sustainable future.

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Artist's concept

The Proposed NISAR Mission — All-Weather Day and Night Imaging

Orbiting radar captures forest volume and biomass over time and with enough detail to reveal changes on hectare scales. Radar penetrates clouds and operates day and night. It produces images that are detailed enough to see local changes, and has broad enough coverage to measure regional trends. The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), would acquire images of ecosystem changes globally. Rapid sampling over years to decades would allow for understanding disturbance, degradation, and response. NISAR's unprecedented coverage in space and time would reveal biomass variability far more comprehensively than any other measurement method. The detailed observations would reveal information that would allow us to better manage resources and prepare for and cope with global change.

Tracking Global Carbon to Improve Climate Change Projections

NISAR measurements would have a major impact on projections of climate change. Ecosystems are sources and sinks for carbon. The total mass of living matter within an environmental area, called biomass, stores carbon and links directly to the carbon cycle. Characterizing biomass globally would refine estimates of the spatial distribution of carbon. The removal of biomass, known as disturbance, can happen abruptly or gradually and can be due to human or natural causes such as forest fires, logging, acid rain, and insect infestations. Recovery or the reestablishment of forests and woody vegetation follows disturbance.

It is not known how Earth's terrestrial biomass is changing and interacting with climate variability. NISAR would be ideally suited to measure woody plants and forest, which make up 80 percent of living terrestrial biomass. NISAR's global, detailed map of aboveground woody biomass density would halve the uncertainty of estimated carbon emissions from land use change.

Understanding the Consequences of Land Use and Climate Change on Ecosystems

Global wetlands and permafrost, which cover nearly a quarter of the northern hemisphere land surface, can have major impacts

on and responses to climate change. Wetlands are one of the most significant natural sources of increased atmospheric methane. When permafrost melts, it releases carbon dioxide and methane, creating further feedback of warming and melt.

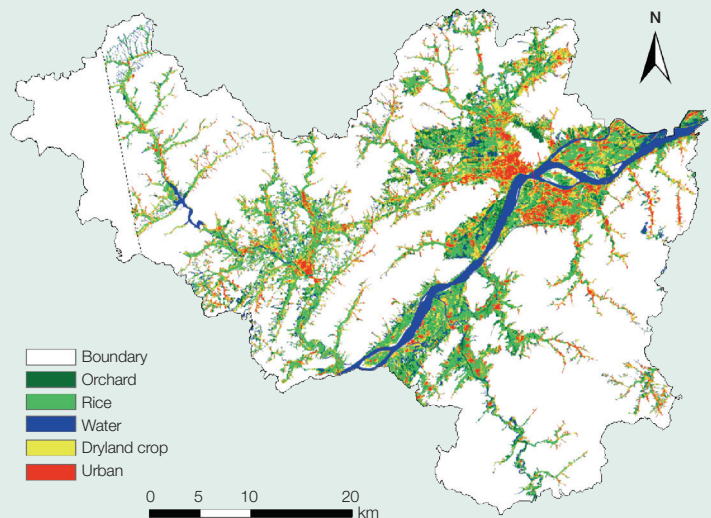
Human-induced disturbances have dramatically altered the terrestrial ecosystems by converting old-growth and carbon-rich forests into permanent croplands and urban landscapes and incurring extensive losses of wetlands (up to 50 percent). These disturbances are also changing the climate with increasing atmospheric CO₂ concentrations, which increases the probability of natural disturbances such as fire, droughts, hurricanes, and storms.

Alpine and mangrove ecosystems respond to change in climate quickly, serving as climatic indicators. Mangroves are a critical coastal ecosystem under severe threat from climate change. Similarly, shifts in vegetation are occurring, especially in high-altitude regions where alpine tree lines are advancing. These changes have important implications for the global carbon cycle and its climate feedback, yet there remains large uncertainty in the global extent and magnitude of these changes in the terrestrial component. NISAR would quantify biomass and track ecosystem changes.

Classifying and Monitoring Crops Using Radar

Radar is effective for classifying crops and has the unique ability to see through clouds. In this image, the Japanese Advanced Land Observing Satellite/Phased Array-type L-band SAR (ALOS/PALSAR) radar imagery was used to produce this crop classification map. The map separates dry and wet crops from forests and urban areas. NISAR could also be used for agricultural monitoring. It could be used to measure changes over the growing season as well as seasonal changes.

The image is from Yuan Zhang, Cuizhen Wang, Jiaping Wu, Jiaguo Qi, and William A. Salas, "Mapping Paddy Rice with Multitemporal ALOS/PALSAR Imagery in Southeast China," *International Journal of Remote Sensing* 30, no. 23 (2009): pp. 6301–6315.



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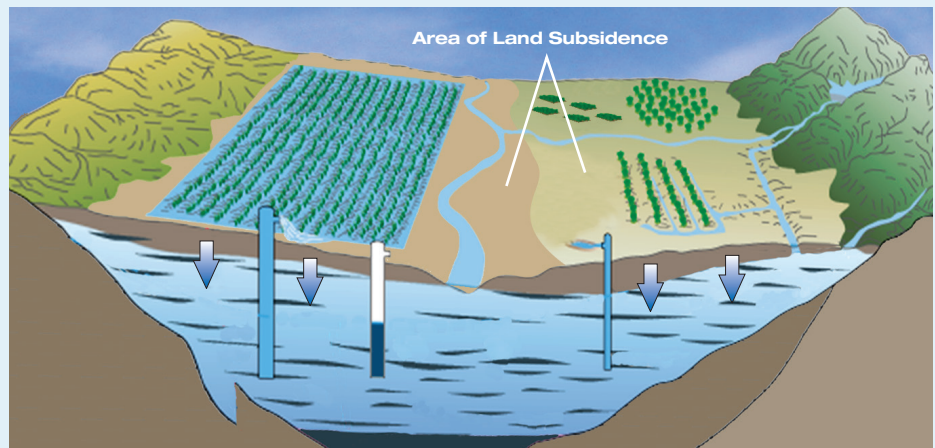


Water: Sustaining Life

NISAR would measure changes in groundwater over the Earth's vulnerable arid regions.

Understanding Aquifer Dynamics

Mapping and monitoring changes in land surface elevation with interferometric synthetic aperture radar (InSAR) may help fill in the gaps between monitoring wells. The ability to map surface deformation of a few millimeters monthly over large areas at resolutions of a few tens of meters has opened up new possibilities for remote monitoring of groundwater resources.

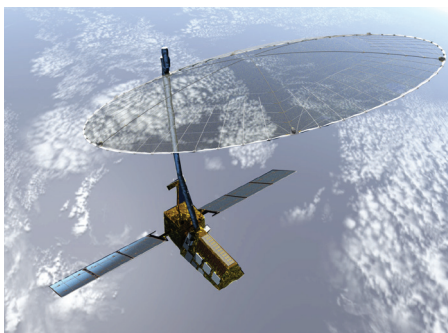


Managing Water Resources

Water is necessary for life, both for drinking and for growing food. In the more arid parts of the world, rainfall and surface water can't satisfy the growing demands of the people who live in those regions. Groundwater makes up the difference, acting as a reservoir that can be tapped through wells. Unfortunately, climate change coupled with growing populations is causing increasing stress on groundwater resources around the world.

Over-exploitation of groundwater leads to lowering of the water table and, in alluvial basins, compaction of aquifers leading to sinking of the land surface (subsidence). Subsidence is often the first indication of over-exploitation and can also cause problems for infrastructure such as aqueducts, flood-control projects, highways, bridges, and railways. If subsidence continues for too long, it can lead to irreversible collapse of the aquifer system, reducing its ability to recharge when water is available.

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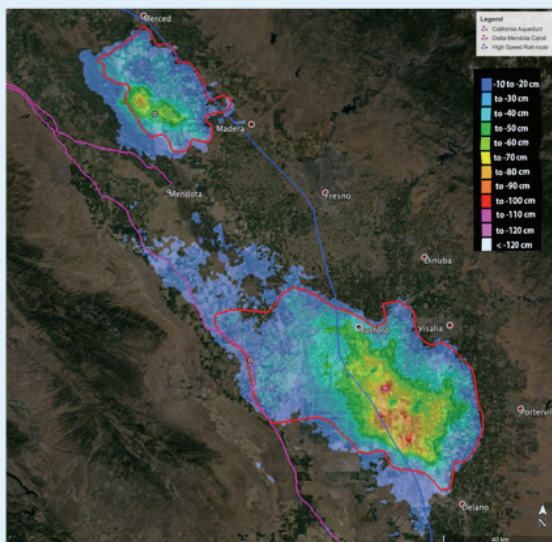
Subsidence As a Measure of Groundwater Depletion

In order to increase resilience and adapt to changes, water resource managers need to be able to detect new areas of subsidence and to monitor known areas of continuing subsidence. This can also give an indication of groundwater depletion over long periods. Currently this is done through periodic leveling surveys and monitoring of water wells, but owing to lack of funds and the difficulty of mandating measurements at private wells, the data are sparse in space and time.

Managing Water Globally

NISAR offers the promise of extending groundwater observations to regions of the world with no effective means to monitor the state of their aquifers. This would provide benefits to large segments of the global population dependent on groundwater to bridge gaps in surface and rain water supply. As Earth's climate changes, monitoring of this critical resource could help reduce conflicts over water. NISAR could also easily map flooded areas, even under vegetation canopies by using its polarimetric mode.

Monitoring Subsidence



Total subsidence in the San Joaquin Valley, California, from 2007 to 2011 measured by InSAR. The subsidence bowl to the north, just south of Merced, is a relatively recent feature caused by a change from row crops to trees, which use more groundwater. Note how the California Aqueduct (purple) and the proposed High Speed Rail (blue) are both affected by subsidence. NISAR would provide this information on a regular basis.

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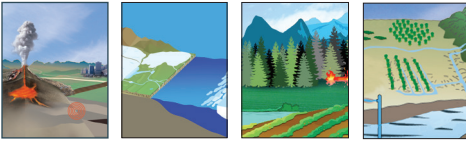
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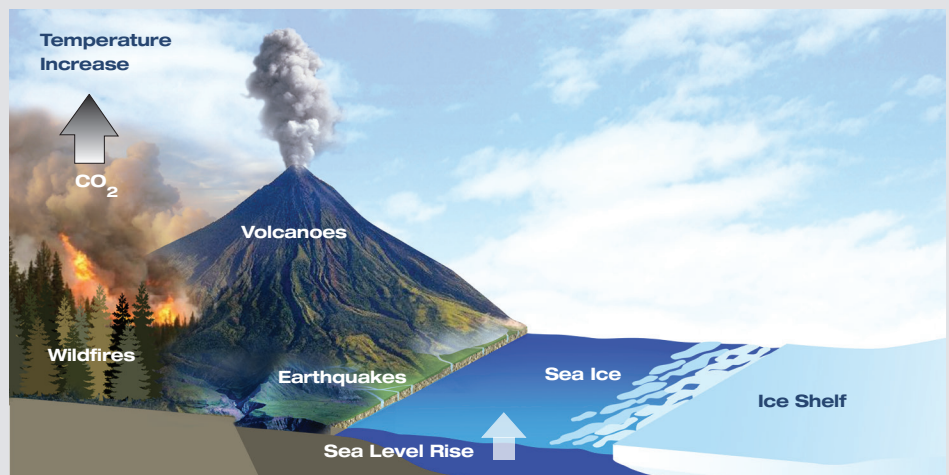


Sensing Our Changing Earth

NISAR would measure Earth's changing ecosystems, dynamic surface, and ice masses, providing information about biomass, natural hazards, sea level rise, and groundwater.

Clarifying Causes and Consequences

The NASA-ISRO Synthetic Aperture Radar, or NISAR, mission would make global measurements of the causes and consequences of land surface changes for integration into Earth system models. NISAR would provide a means to measure and clarify processes ranging from ecosystem disturbances to ice sheet collapse and natural hazards including earthquakes, tsunamis, volcanoes, and landslides.

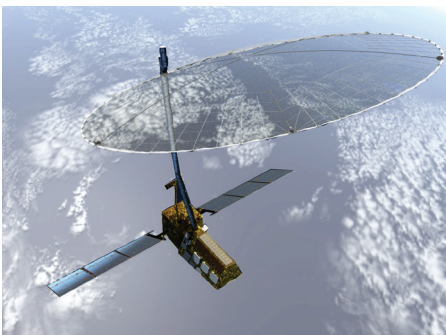


Monitoring Earth's Changing Surface

Earth's land surface is constantly changing and interacting with its interior and atmosphere. The causes and consequences of change on the Earth's surface are complex and interrelated. Changing land use impacts the carbon cycle, which modifies Earth's climate, causing retreat of ice masses, in turn raising sea level, and resulting in altered coastlines. The impacts of a changing climate at the Earth's surface can include subsidence

from water withdrawal or melting permafrost, landslides from increased storm activity, and changes to shipping lanes from a reduction of sea ice. Natural hazards such as volcanoes and earthquakes further shape the land surface and can have devastating impacts to human populations.

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Artist's concept

The Proposed NISAR Mission — All-Weather Day and Night Imaging

The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission would acquire radar images of surface changes globally. Rapid sampling over the lifetime of the mission would allow for understanding Earth processes and change. Radar penetrates clouds and operates day and night, enabling reliable and continuous monitoring at all times. Orbiting radar captures images of the movements of the Earth's surface, and land and sea ice over time, revealing subtle changes in the surface as well as what is happening below the surface. It captures forest volume and biomass over time and with enough detail to reveal changes on human scales. It produces images with sufficient resolution to see local changes and has broad enough coverage to monitor regional events. Detailed observations would allow us to better manage resources and prepare for and cope with hazards and global change.

Addressing an Increasing Exposure to Natural Disasters

NISAR would measure surface changes to determine the likelihood of earthquakes, volcanic eruptions, and landslides. Earthquakes and volcanoes cause billions of dollars in damage and loss of life. Geologists say the Pacific Northwest and California are due for large earthquakes. Populations are increasing in high-risk areas vulnerable to sea level change, land subsidence, tsunamis, volcanoes, earthquakes, and landslides. Improved forecasting and mitigation necessitates understanding these natural hazards, with measurements throughout the hazard cycle.

Tracking Global Carbon and Understanding Land Use

NISAR would determine the contribution of Earth's most variable biomass to the global carbon budget and characterize ecosystem disturbance and impacts on biodiversity. Landscapes are rapidly changing as forests are cut down and agricultural lands are developed. Land ecosystems, which act as carbon sources and sinks, must be studied now for us to understand how they may interact with climate as atmospheric CO₂ increases.

Assessing Society's Exposure to Diminishing Ice

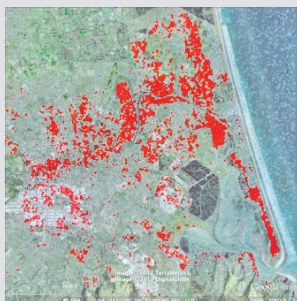
NISAR would determine how climate to ice masses interrelate and raise sea level and would measure changes in sea ice, snow extent, permafrost, and surface melting. Ice sheets, sea ice, and glaciers, which are key indicators of climate effects, are undergoing dramatic changes. Rising sea level from melting ice sheets poses hazards to coastal areas from storm surges and erosion. Diminishing sea ice is changing shipping lanes and availability of resources. Measurements now will be used to predict future changes.

Monitoring Earth's Reservoirs

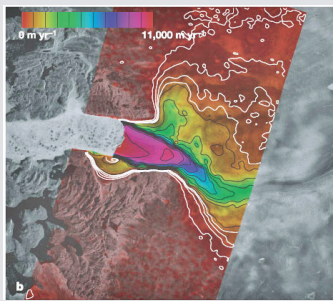
NISAR would monitor hydrocarbon and sequestered CO₂ reservoirs, and measure changes in groundwater over the Earth's vulnerable arid regions. Informed decisions allow us to make the most of our resources sustainably and economically. By measuring changes of the Earth's surface, we can understand processes occurring below the surface and impacts. Subsidence is often the first indication of changes in reservoirs or over-exploitation of aquifers. Subsidence that continues for too long can lead to irreversible collapse of the aquifer system.

Addressing Society's Needs

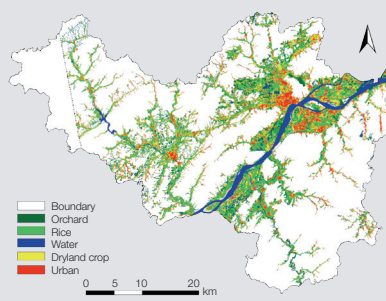
Earthquakes



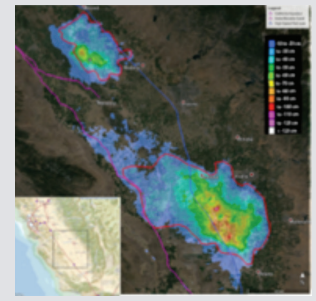
Glaciers



Crops



Subsidence



U.S. losses from earthquakes are \$5B/year and the economic impact of sea level rise on the U.S. will exceed \$20B.

Radar can be used to produce damage maps after earthquakes (left), determine the speed of glaciers (middle left), classify crops (middle right), and monitor subsidence

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